Unit 9
Animal Form and Function
Chapter 38: Nervous and Sensory Systems

Overview: Sense and Sensibility

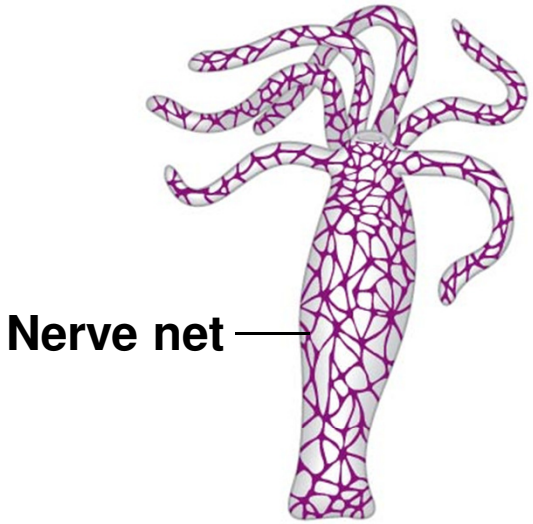
- Gathering, processing, and organizing information are essential functions of all nervous systems

Concept 38.1: Nervous systems consist of circuits of neurons and supporting cells

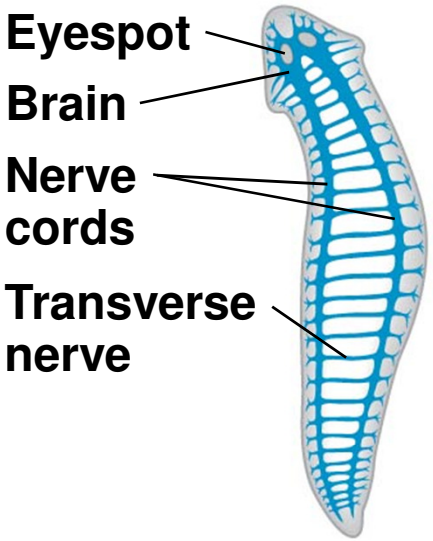
- In most cnidarians, interconnected nerve cells form a **nerve net**
  - Controls contraction and expansion of the gastrovascular cavity
- In more complex animals, the axons of multiple nerve cells are often bundled together to form **nerves**
  - These fibrous structures channel and organize information flow through the nervous system

- Animals with elongated, bilaterally symmetrical bodies have even more specialized systems
- *Cephalization* is an evolutionary trend toward a clustering of sensory neurons and interneurons at the anterior
- Nonsegmented worms have the simplest clearly defined *central nervous system*, consisting of a small brain and longitudinal nerve cords
- Annelids and arthropods have segmentally arranged clusters of neurons called *ganglia*
- In vertebrates
  - The **central nervous system** (**CNS**) is composed of the brain and spinal cord
  - The **peripheral nervous system** (**PNS**) is composed of nerves and ganglia

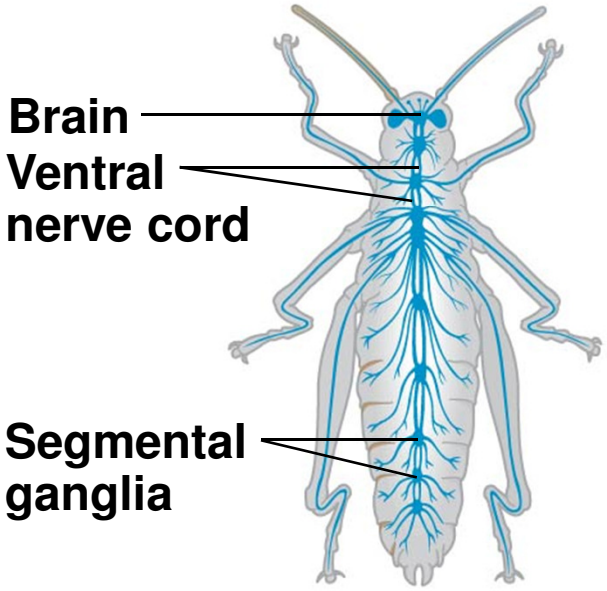
Figure 38.2



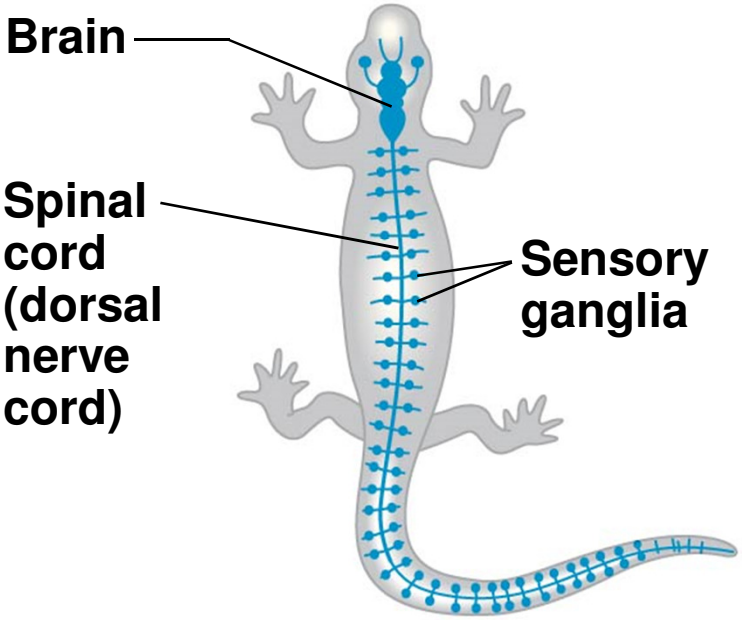
(a) Hydra (cnidarian)



(b) Planarian (flatworm)



(c) Insect (arthropod)

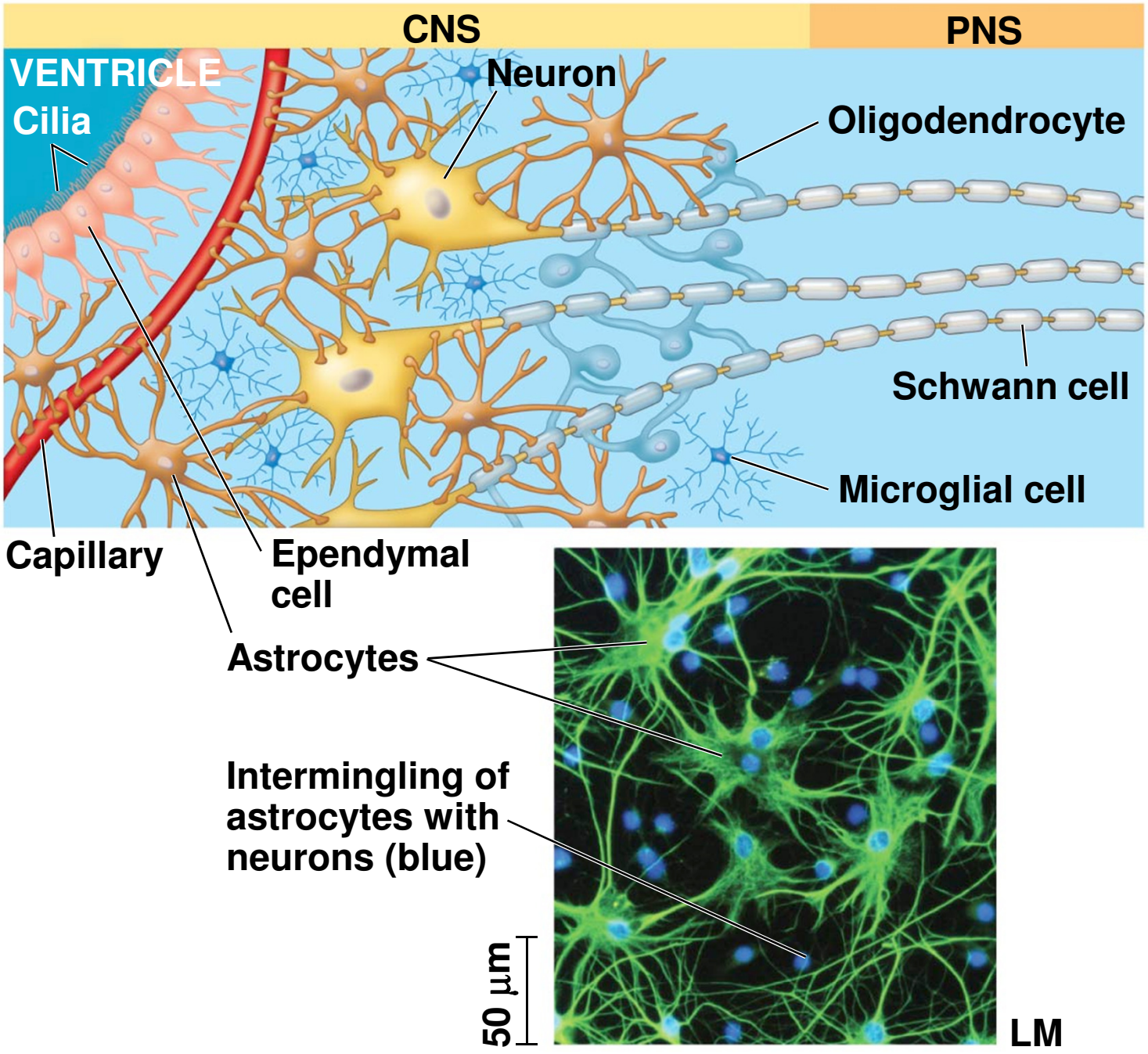


(d) Salamander (vertebrate)

Glia

- Glia have numerous functions to nourish, support, and regulate neurons
  - **Astrocytes** (star-shaped glial cells) induce cells lining capillaries in the CNS to form tight junctions, resulting in a blood-brain barrier
    - Separates extracellular environment of CNS and circulatory system
    - Restricts movement of most substances from blood to brain

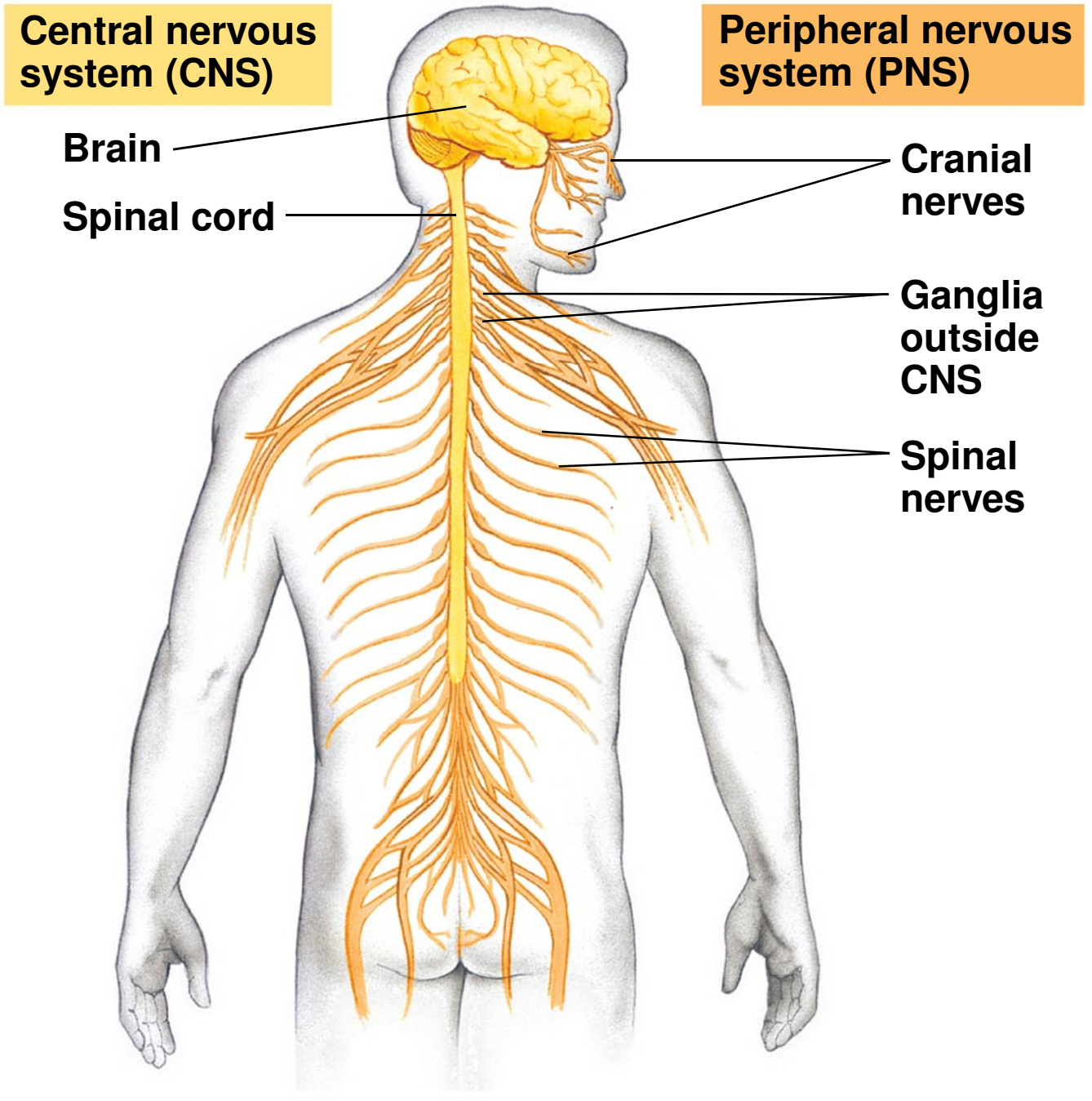
Figure 38.3


CNS
PNS
VENTRICLE
Cilia
Neuron
Oligodendrocyte
Schwann cell
Microglial cell
Capillary
Ependymal cell
Astrocytes
Intermingling of astrocytes with neurons (blue)
50 µm
LM

Organization of the Vertebrate Nervous System

- The spinal cord runs lengthwise inside the vertebral column (the spine)
  - Conveys information to and from the brain
  - Generates basic patterns of locomotion
  - Can also act independently of the brain as part of simple nerve circuits that produce **reflexes**
    - The body's automatic responses to certain stimuli

Figure 38.4


Central nervous system (CNS)
Peripheral nervous system (PNS)
Brain
Spinal cord
Cranial nerves
Ganglia outside CNS
Spinal nerves

- The brain and spinal cord contain
  - **Gray matter**, which consists mainly of neuron cell bodies and glia
  - **White matter**, which consists of bundles of myelinated axons
    - Makes up outer layer in spinal cord
      - Links CNS to PNS
    - Located in interior of brain
      - Signaling functions in learning, emotions, processing sensory info, and generating commands

- The CNS contains fluid-filled spaces called *ventricles* in the brain and the *central canal* in the spinal cord
- *Cerebrospinal fluid* is formed in the brain and circulates through the ventricles and central canal and drains into the veins
  - Supplies the CNS with nutrients and hormones and carries away wastes
  - Cushions the brain

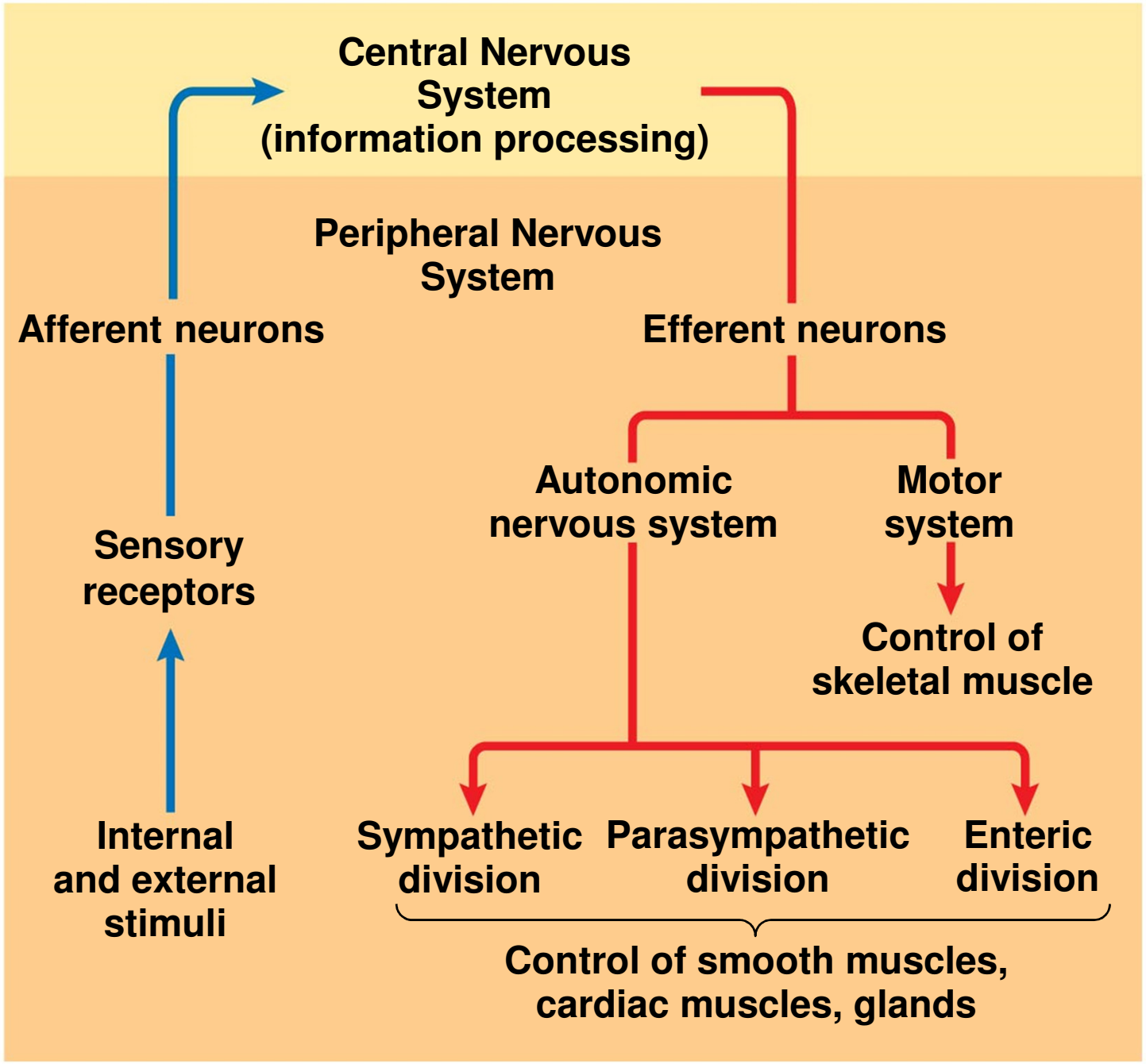
The Peripheral Nervous System

- The PNS transmits information to and from the CNS and regulates movement and the internal environment
  - *Afferent* neurons transmit information to the CNS
  - *Efferent* neurons transmit information away from the CNS

- The PNS has two efferent components:
  - The **motor system** carries signals to skeletal muscles
    - Can be voluntary or involuntary
  - The **autonomic nervous system** regulates smooth and cardiac muscles
    - Generally involuntary

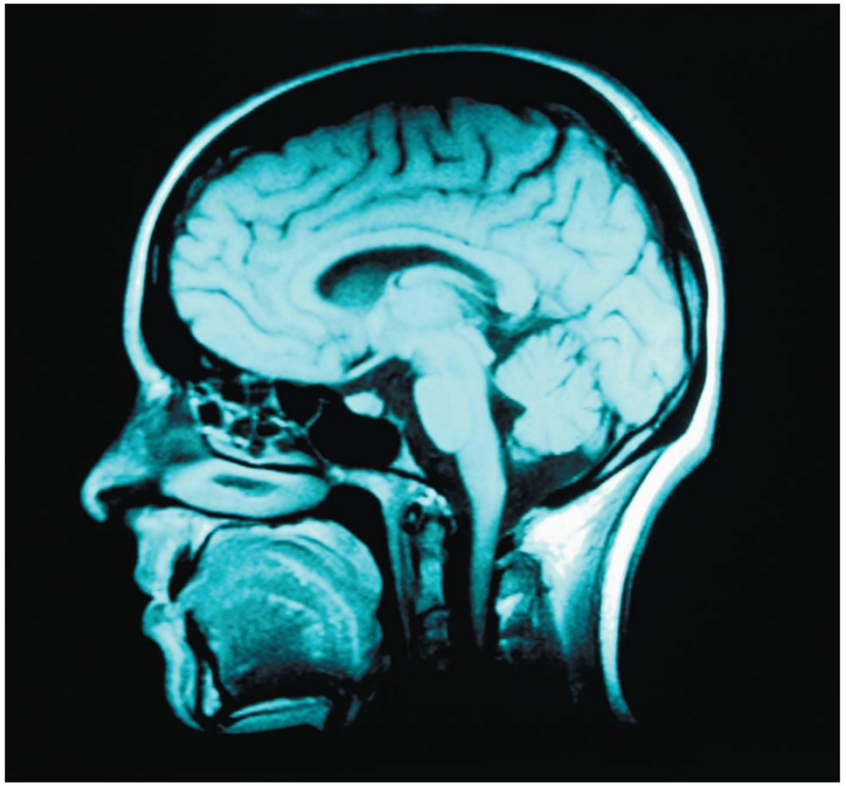
- The autonomic nervous system has 3 divisions:
  - The **enteric division** controls activity of the digestive tract, pancreas, and gallbladder
  - The **sympathetic division** regulates the “fight-or-flight” response
  - The **parasympathetic division** generates opposite responses in target organs and promotes calming and a return to “rest and digest” functions

Figure 38.5


Central Nervous System (information processing)
Peripheral Nervous System
Afferent neurons
Efferent neurons
Sensory receptors
Autonomic nervous system
Motor system
Control of skeletal muscle
Internal and external stimuli
Sympathetic division
Parasympathetic division
Enteric division
Control of smooth muscles, cardiac muscles, glands

Concept 38.2: The vertebrate brain is regionally specialized

- The human brain contains 100 billion neurons
- These cells are organized into circuits that can perform highly sophisticated information processing, storage, and retrieval



Exploring the Organization of the Human Brain

- **Cerebrum**
  - Dorsal portion of vertebrate forebrain
  - Controls skeletal muscle contraction
    - Motor cortex
  - Integrating center for learning, emotion, memory, and perception
    - Calculation, contemplation, and cognition
  - Surface of cerebrum is called the **cerebral cortex**
    - Vital for perception, voluntary movement, and learning

- Divided into 2 hemispheres
  - Left side receives info from and controls movement of right side of body and vice versa
  - **Corpus callosum** connects them, enabling them to process info together

- **Cerebellum**
  - Part of vertebrate hindbrain
    - Located dorsally
  - Coordinates movement and balance
    - Hand-eye coordination
  - Helps in learning and remembering motor skills

- **Diencephalon** gives rise to
  - **Thalamus**
    - Main input center for sensory info going to cerebrum
  - **Hypothalamus**
    - Functions as thermostat
    - Central biological clock
    - Regulates pituitary gland
      - Regulates hunger and thirst
      - Plays a role in mating behaviors
      - Initiates fight-or-flight response
  - Epithalamus
    - Includes pineal gland (source of melatonin)

- **Brainstem** consists of
  - Midbrain
    - Relay station for info traveling between PNS and cerebrum
    - Coordinates hearing and visual reflexes
  - **Pons**
    - Regulates sleep and arousal
  - **Medulla oblongata**
    - Controls several automatic, homeostatic functions
      - Breathing
      - Heart rate and blood vessel activity
      - Swallowing, vomiting, digestion

Figure 38.6b

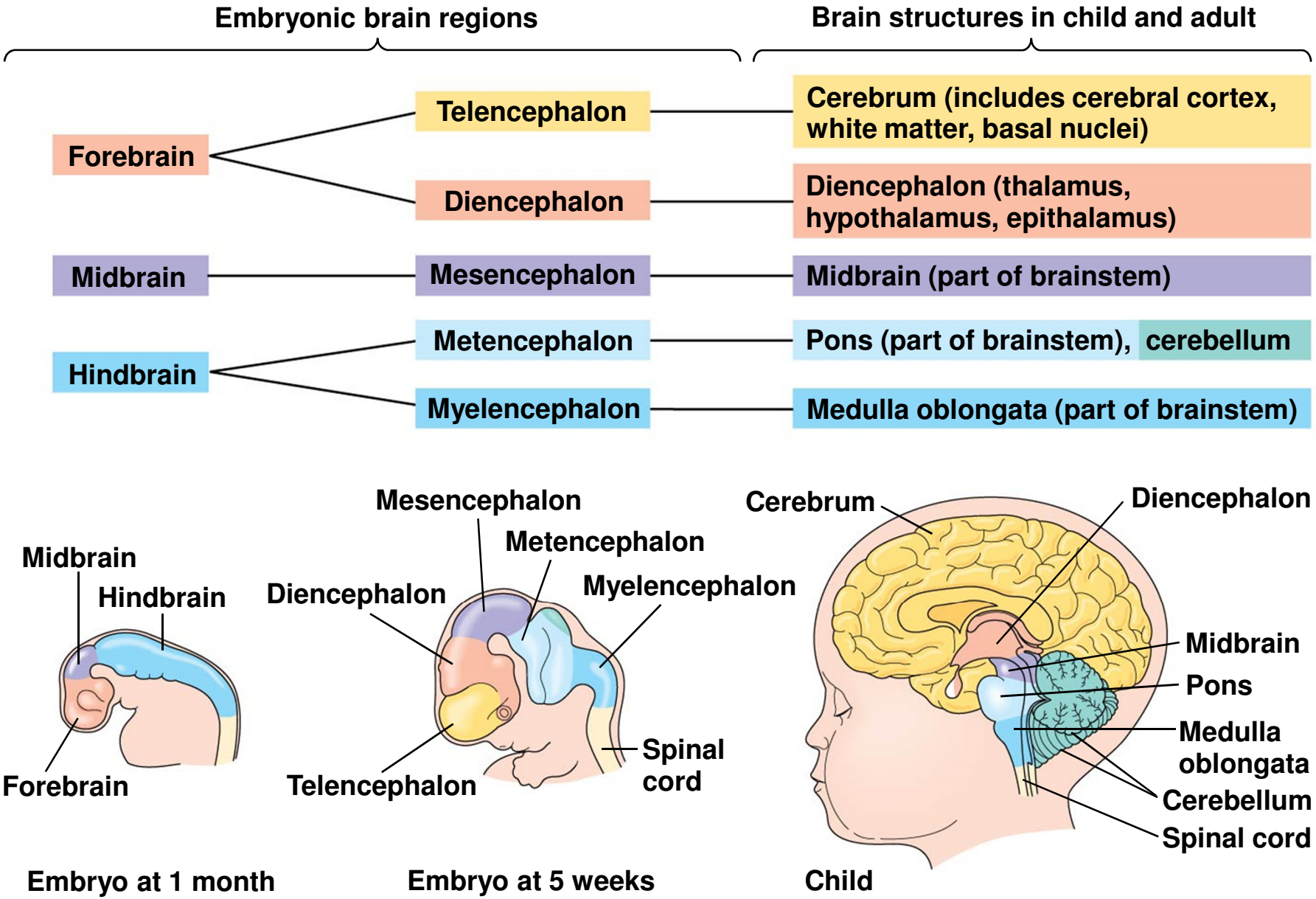
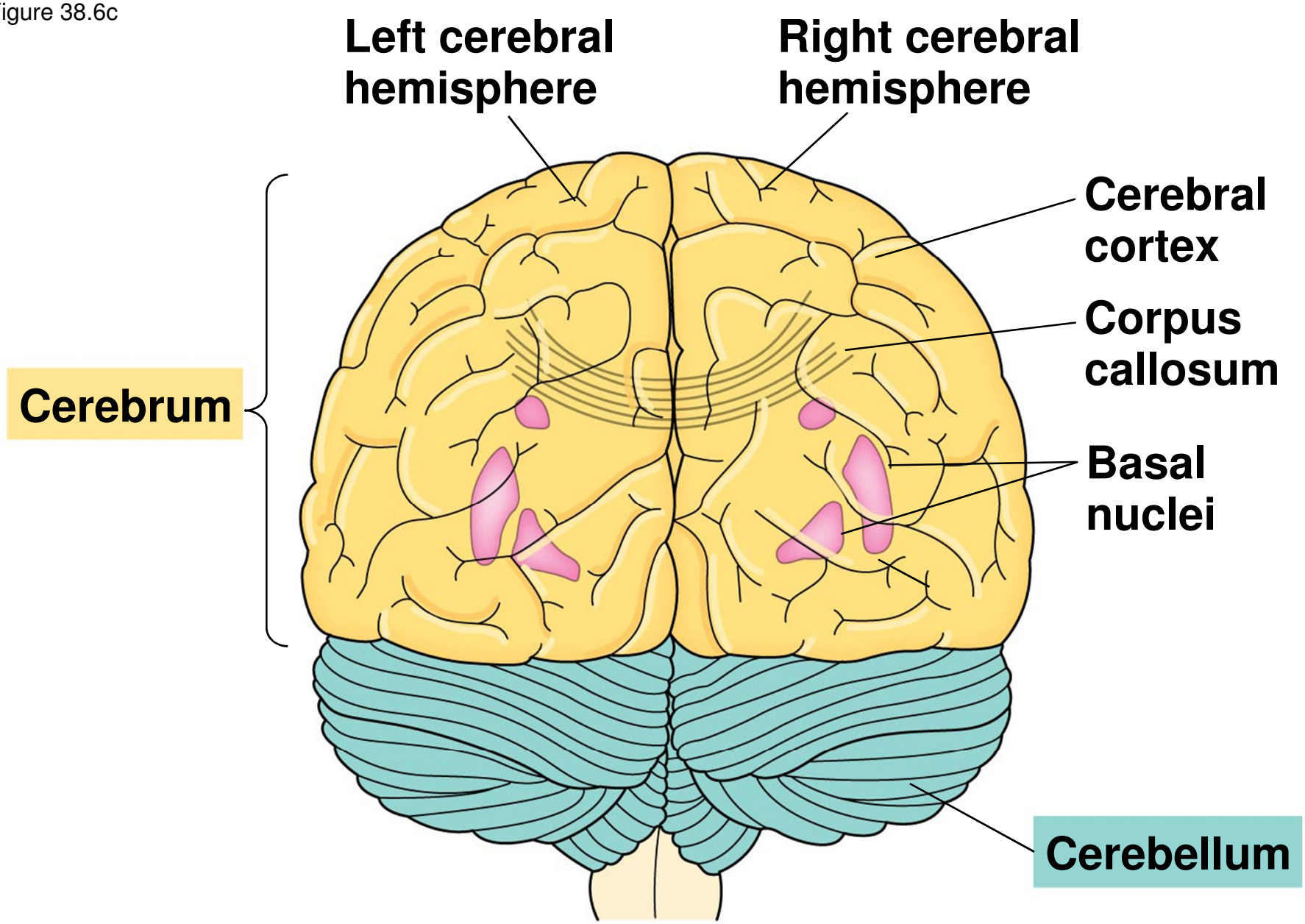
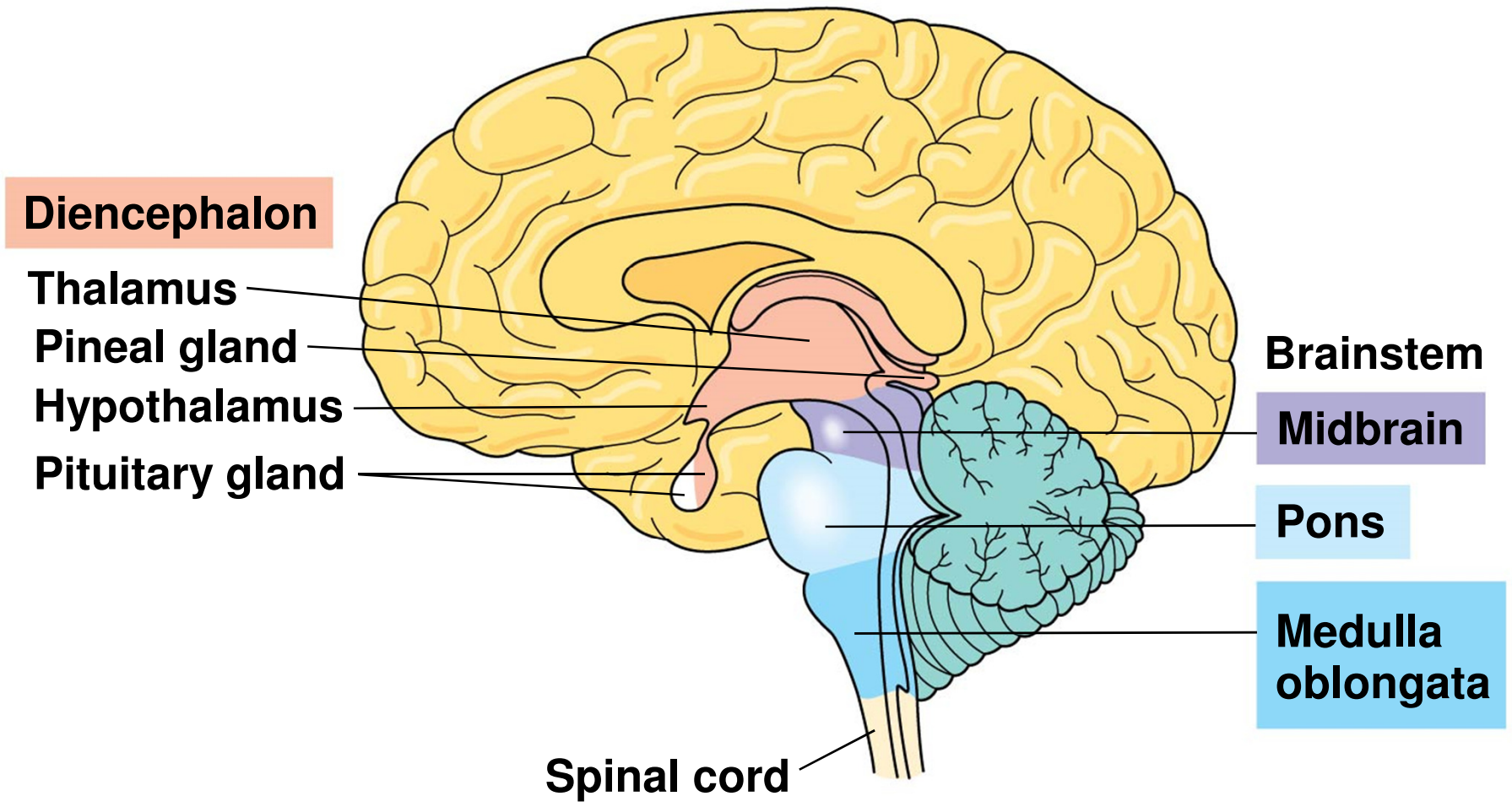

Embryonic brain regions
Brain structures in child and adult
Forebrain
Telencephalon
Cerebrum (includes cerebral cortex, white matter, basal nuclei)
Diencephalon
Diencephalon (thalamus, hypothalamus, epithalamus)
Midbrain
Mesencephalon
Midbrain (part of brainstem)
Hindbrain
Metencephalon
Pons (part of brainstem), cerebellum
Myelencephalon
Medulla oblongata (part of brainstem)
Midbrain
Hindbrain
Forebrain
Embryo at 1 month
Mesencephalon
Metencephalon
Diencephalon
Myelencephalon
Spinal cord
Telencephalon
Embryo at 5 weeks
Cerebrum
Diencephalon
Midbrain
Pons
Medulla oblongata
Cerebellum
Spinal cord
Child

Figure 38.6c



Adult brain viewed from the rear

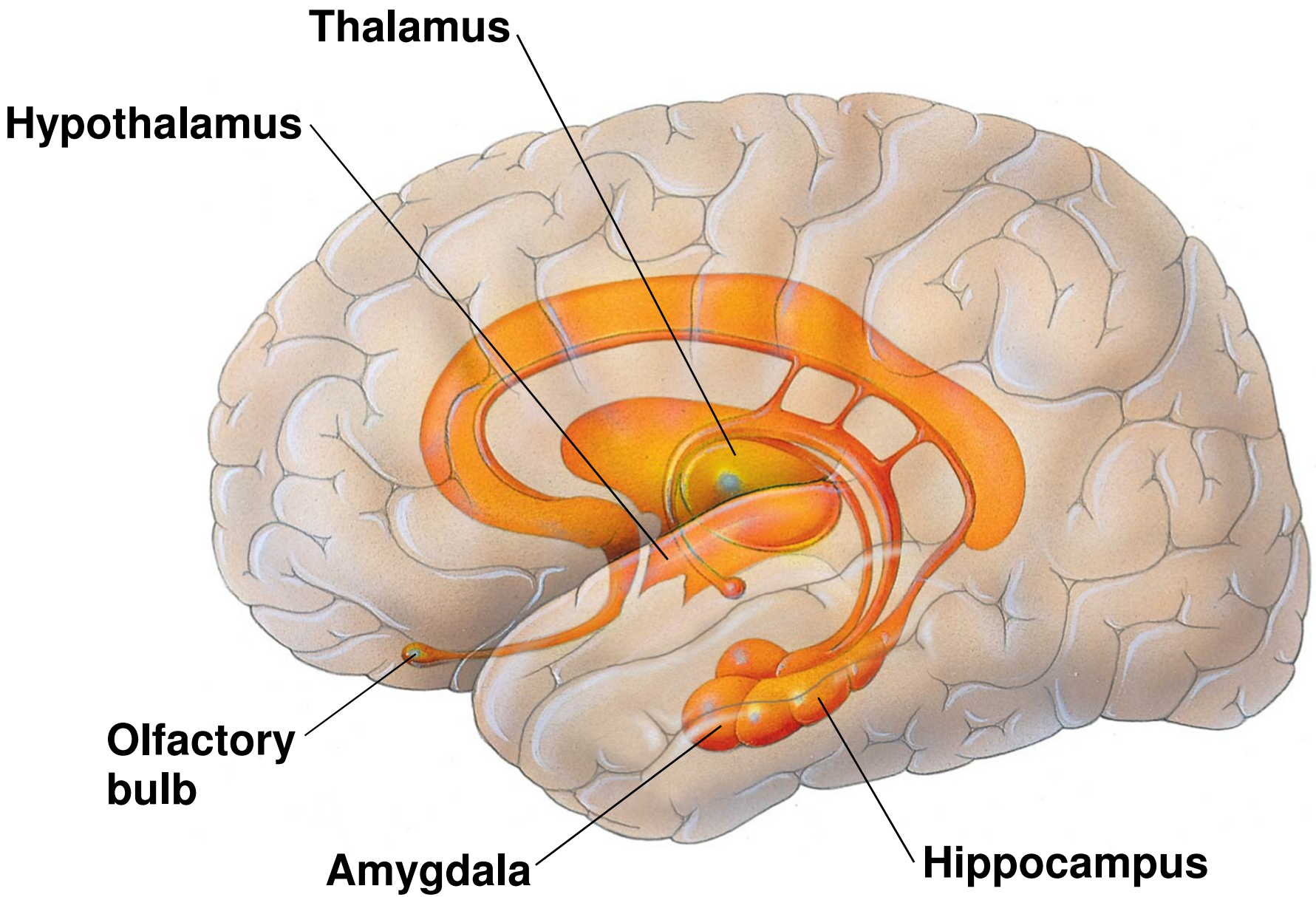
Figure 38.6d


Diencephalon
Thalamus
Pineal gland
Hypothalamus
Pituitary gland
Brainstem
Midbrain
Pons
Medulla oblongata
Spinal cord

Emotions

- Generation and experience of emotions involve many brain structures including the amygdala, hippocampus, and parts of the thalamus
  - These structures are grouped as the *limbic system*
- Generation and experience of emotion also require interaction between the limbic system and sensory areas of the cerebrum
- The brain structure that is most important for emotional memory is the amygdala

Figure 38.8

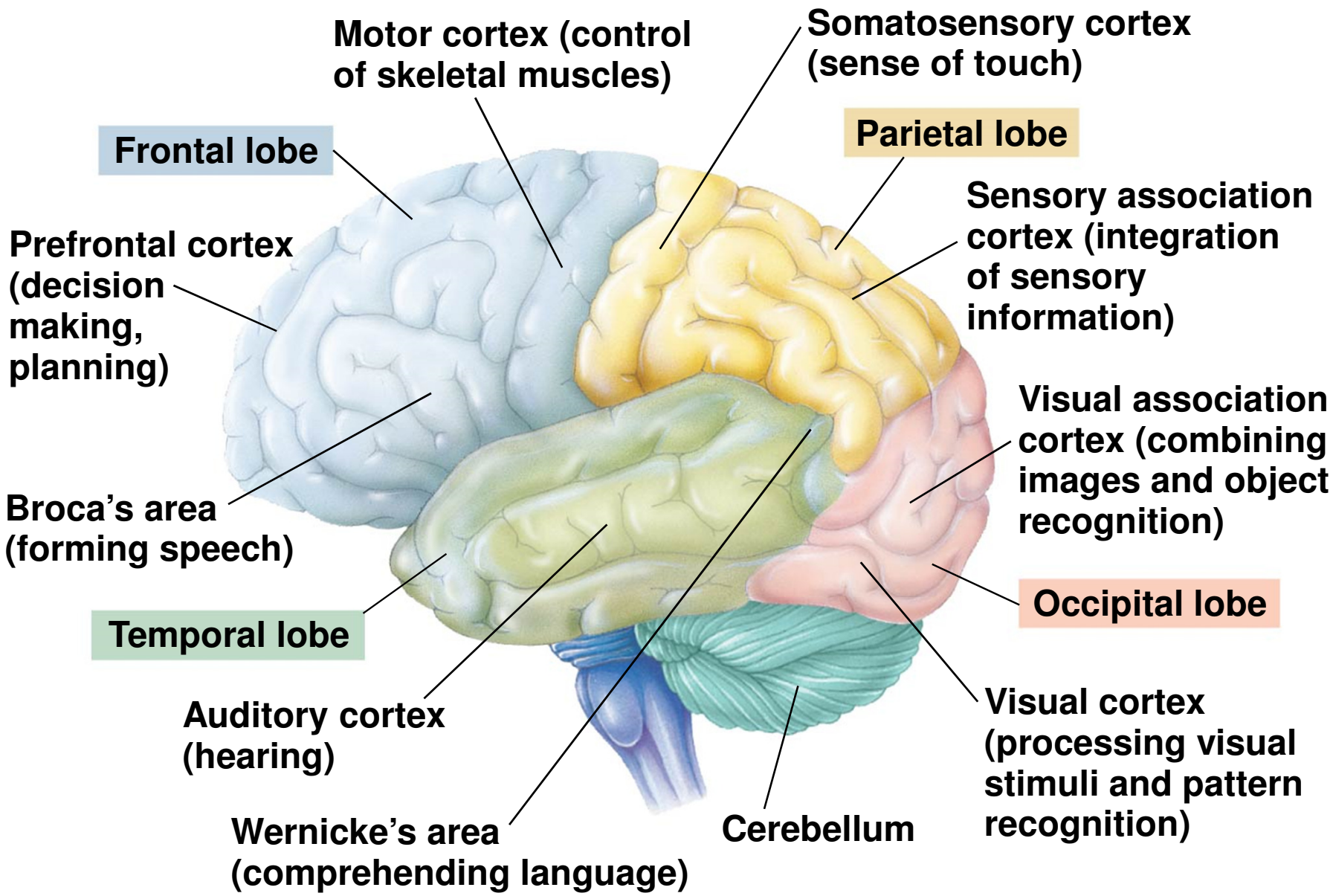

Thalamus
Hypothalamus
Olfactory bulb
Amygdala
Hippocampus

Concept 38.3: The cerebral cortex controls voluntary movement and cognitive functions

- The cerebrum is essential for
  - Language
  - Cognition
  - Memory
  - Consciousness
  - Awareness of our surroundings
- The cognitive functions reside mainly in the cortex, the outer layer

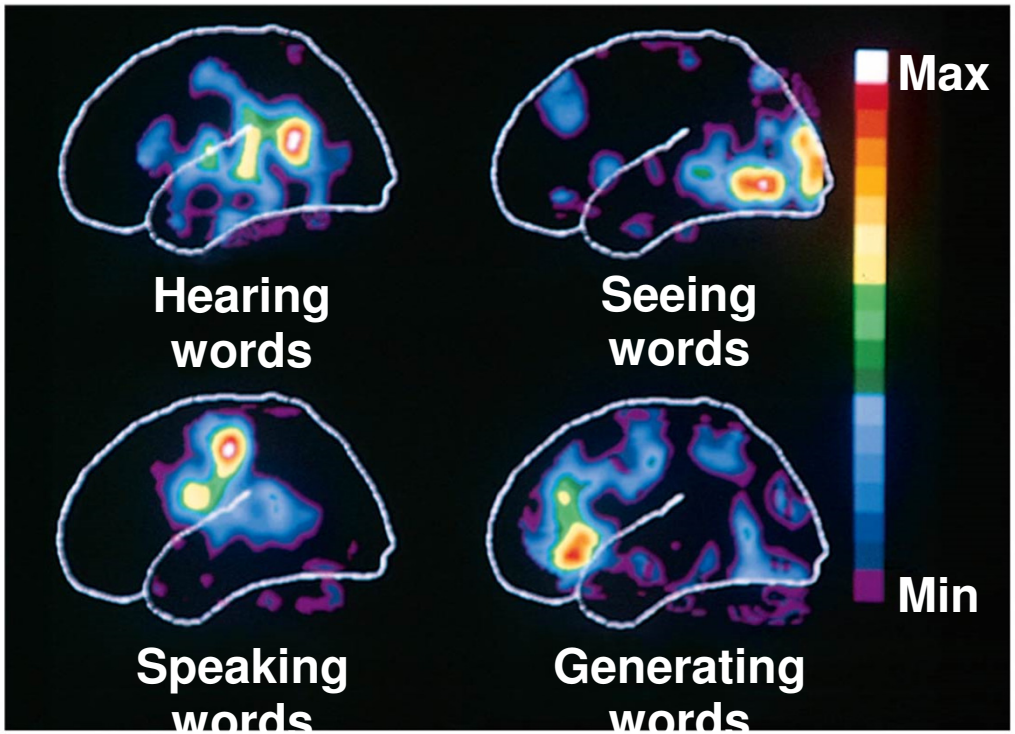
- Four regions, or *lobes*, are landmarks for particular functions
  - Frontal
    - Decision making, reasoning, cognition,
    - Motor skills
  - Temporal - Auditory
  - Occipital - Visual
  - Parietal - Tactile

Figure 38.11


Motor cortex (control of skeletal muscles)
Somatosensory cortex (sense of touch)
Frontal lobe
Parietal lobe
Prefrontal cortex (decision making, planning)
Sensory association cortex (integration of sensory information)
Visual association cortex (combining images and object recognition)
Broca's area (forming speech)
Occipital lobe
Temporal lobe
Auditory cortex (hearing)
Visual cortex (processing visual stimuli and pattern recognition)
Wernicke's area (comprehending language)
Cerebellum

Language and Speech

- *Broca's area* is active when speech is generated
  - In left frontal lobe
- *Wernicke's area* is active when speech is heard
  - In posterior of the left temporal lobe



Lateralization of Cortical Function

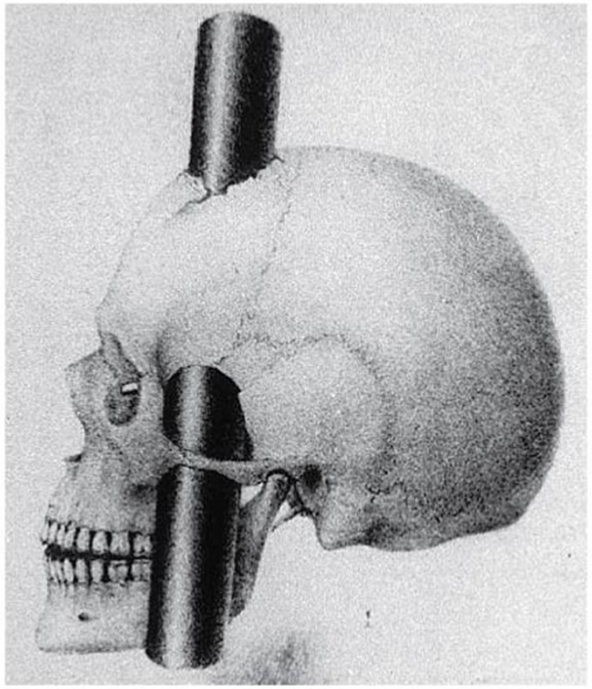
- The left side of the cerebrum is dominant regarding language, math, and logical operations
- The right hemisphere is dominant in recognition of faces and patterns, spatial relations, and nonverbal thinking
- The establishment of differences in hemisphere function is called **lateralization**
- The two hemispheres exchange information through the fibers of the corpus callosum

Information Processing

- The cerebral cortex receives input from sensory organs and *somatosensory* receptors
  - Somatosensory receptors provide information about touch, pain, pressure, temperature, and the position of muscles and limbs
- The thalamus directs different types of input to distinct locations

Frontal Lobe Function

- Frontal lobe damage may impair decision making and emotional responses but leave intellect and memory intact
- The frontal lobes have a substantial effect on "executive functions"



Neural Plasticity

- **Neural plasticity** is the capacity of the nervous system to be modified after birth
- Changes can strengthen or weaken signaling at a synapse
- Autism, a developmental disorder, involves a disruption of activity-dependent remodeling at synapses
  - Children with autism display impaired communication and social interaction, as well as stereotyped and repetitive behaviors

Memory and Learning

- Neural plasticity is essential to formation of memories
- We hold information for a time in **short-term memory** and then release it if it becomes irrelevant
  - Accessed via the *hippocampus*
- **Long-term memory** is activated when we hold, associate, and recall information
  - Links in the hippocampus are replaced by connections within the cerebral cortex itself

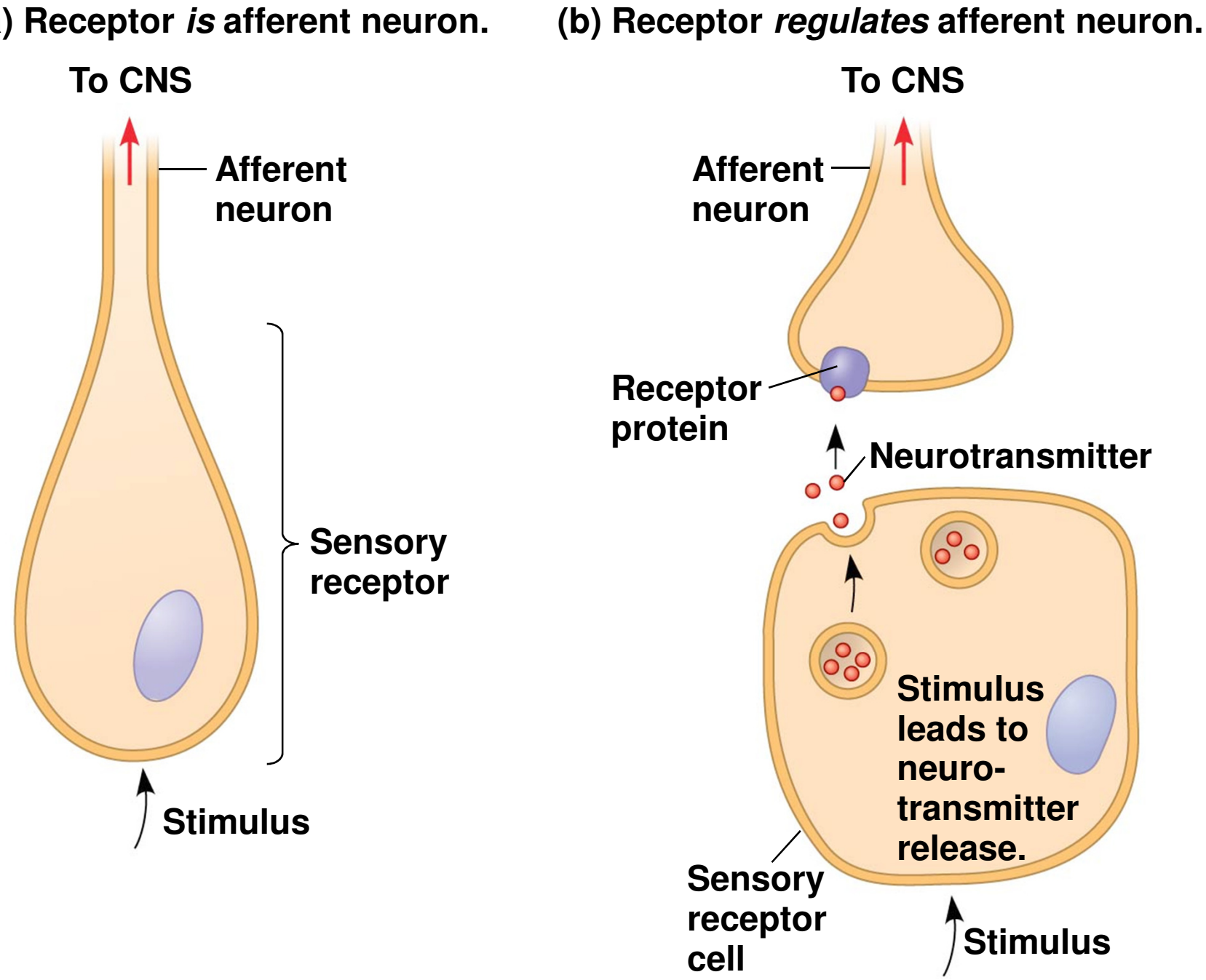
Concept 38.4: Sensory receptors transduce stimulus energy and transmit signals to the central nervous system

- Much brain activity begins with sensory input
- A sensory receptor detects a stimulus, which alters the transmission of action potentials to the CNS
- The information is decoded in the CNS, resulting in a sensation

Sensory Reception and Transduction

- A sensory pathway begins with **sensory reception**
  - Detection of stimuli by **sensory receptors** that interact directly with stimuli, both inside and outside the body
- **Sensory transduction** is the conversion of stimulus energy into a change in the membrane potential of a sensory receptor
- This change in membrane potential is called a **receptor potential**
  - Receptor potentials are graded
    - Their magnitude varies with the strength of the stimulus

Figure 38.15

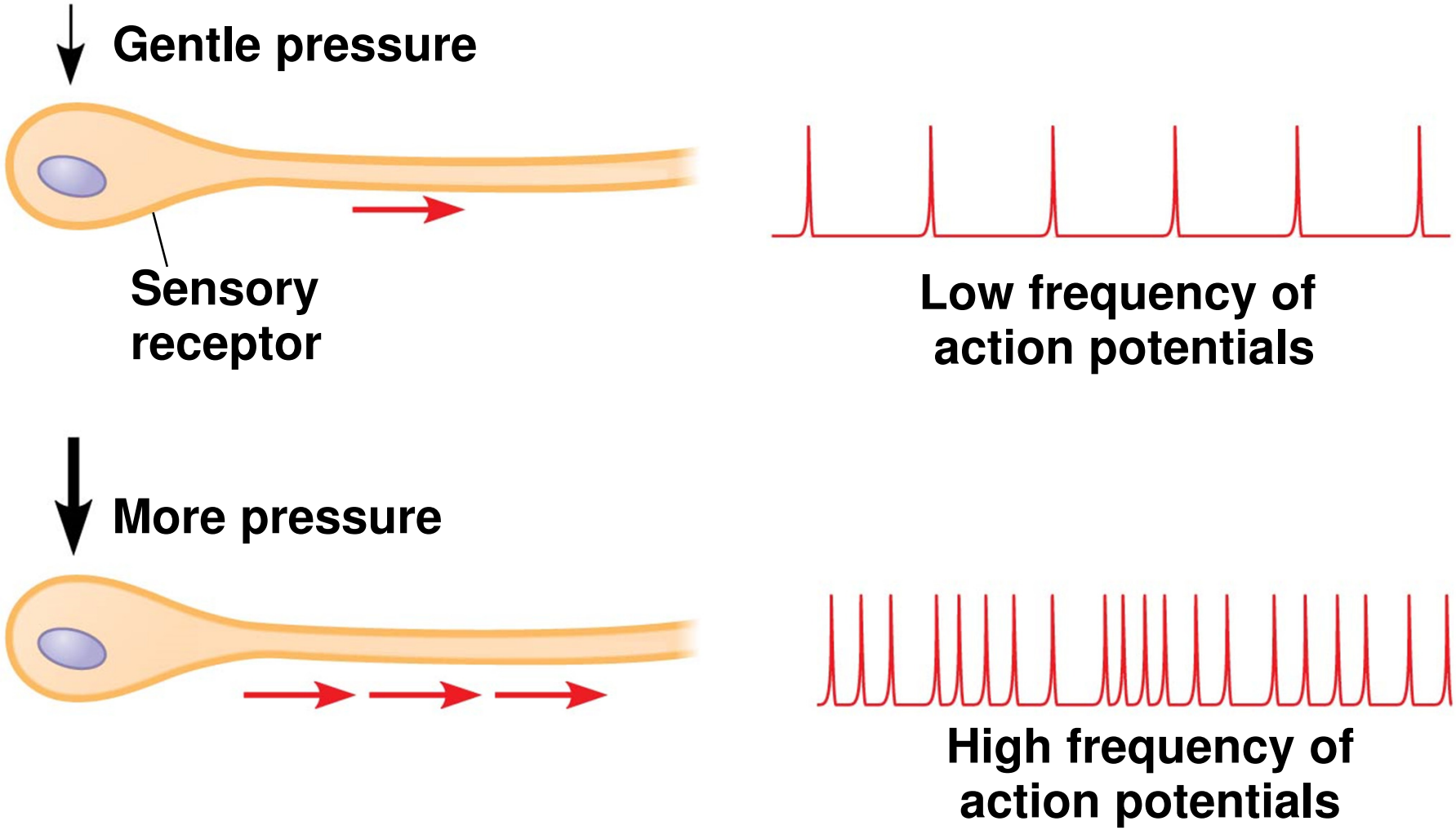

(a) Receptor *is* afferent neuron.
To CNS
Afferent neuron
Sensory receptor
Stimulus
(b) Receptor *regulates* afferent neuron.
To CNS
Afferent neuron
Receptor protein
Neurotransmitter
Stimulus leads to neuro-transmitter release.
Sensory receptor cell
Stimulus

Transmission

- Sensory information is transmitted as nerve impulses, or action potentials
- Neurons that act directly as sensory receptors produce action potentials and have an axon that extends into the CNS
- Non-neuronal sensory receptors form chemical synapses with sensory neurons
- They typically respond to stimuli by increasing the rate at which the sensory neurons produce action potentials

- The response of a sensory receptor varies with intensity of stimuli
- If the receptor is a neuron, a larger receptor potential results in more frequent action potentials
- If the receptor is not a neuron, a larger receptor potential causes more neurotransmitter to be released

Figure 38.16


Gentle pressure
Sensory receptor
Low frequency of action potentials
More pressure
High frequency of action potentials

Perception

- **Perception** is the brain's construction of stimuli
  - Circuits of neurons process the input
- Action potentials from sensory receptors travel along neurons that are dedicated to a particular stimulus
  - The brain thus distinguishes stimuli, such as light or sound, solely by the path along which the action potentials have arrived

Amplification and Adaptation

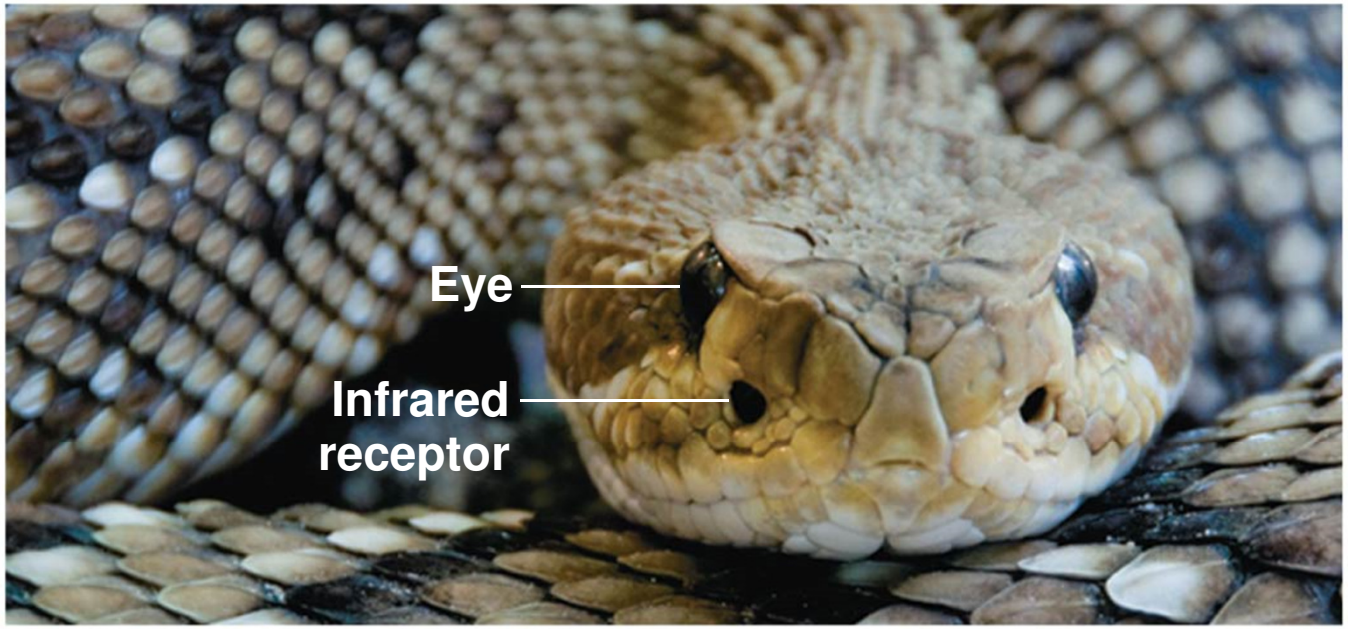
- **Amplification** is the strengthening of stimulus energy by cells in sensory pathways
  - Often requires second messengers
- **Sensory adaptation** is a decrease in responsiveness to continued stimulation
  - Otherwise you would be constantly aware of feeling every beat of your heart and all of the clothing you are wearing

Types of Sensory Receptors

- Based on energy transduced, sensory receptors fall into five categories
  - Mechanoreceptors
  - Electromagnetic receptors
  - Thermoreceptors
  - Pain receptors
  - Chemoreceptors

- **Mechanoreceptors** sense physical deformation caused by stimuli such as pressure, touch, stretch, motion, and sound
  - Ex: Sensitive whiskers
- **Electromagnetic receptors** detect electromagnetic energy such as light, electricity, and magnetism
  - Some snakes have very sensitive infrared receptors that detect body heat of prey
  - Many animals apparently migrate using Earth's magnetic field to orient themselves

Figure 38.17



(a) Rattlesnake

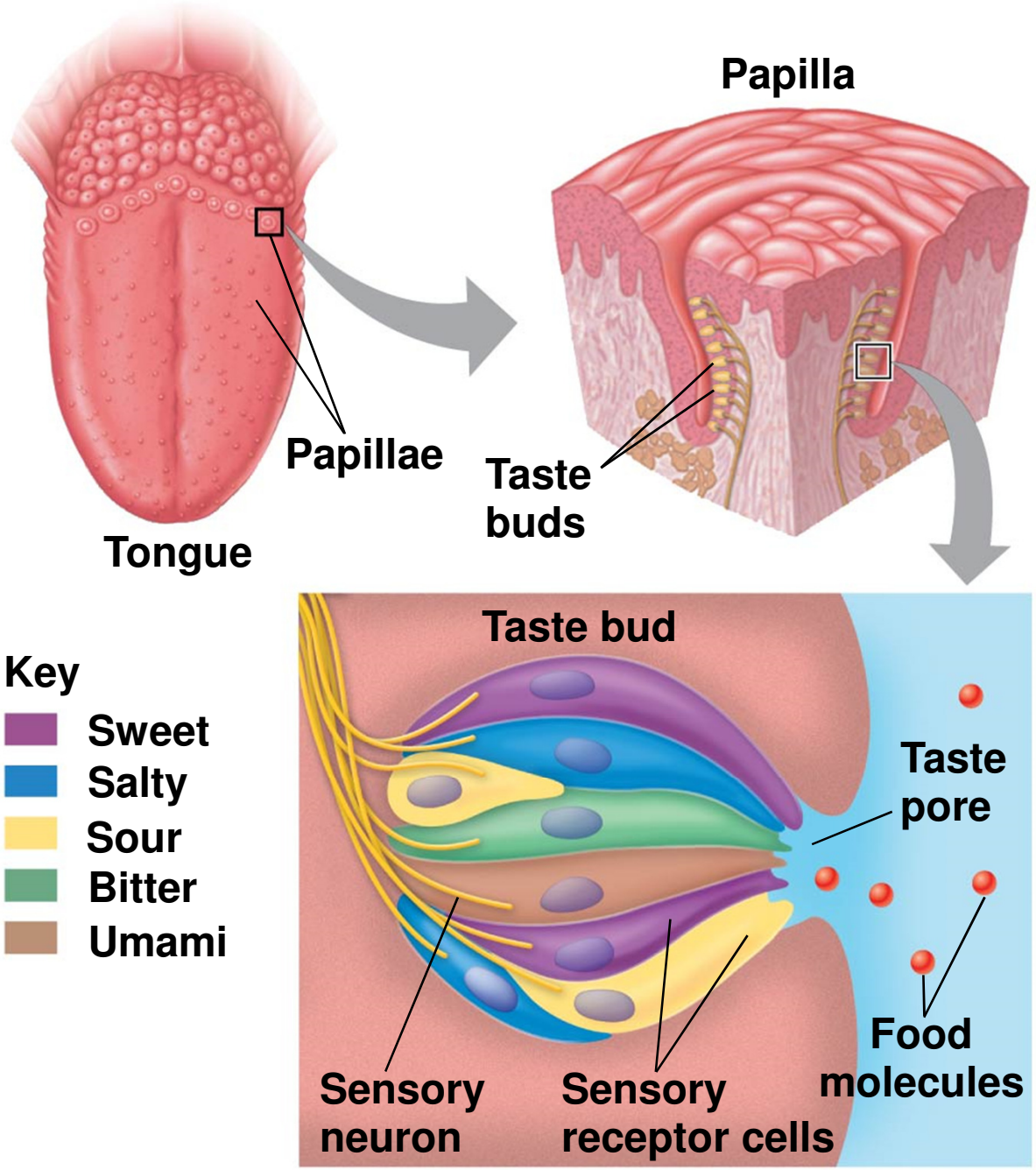
(b) Beluga whales

- **Thermoreceptors** detect heat and cold
  - In humans, thermoreceptors in the skin and anterior hypothalamus send information to the body's thermostat in the posterior hypothalamus
- In humans, **nociceptors**, or pain receptors detect stimuli that reflect harmful conditions that could damage animal tissues
  - By triggering defensive reactions, such as withdrawal from danger, pain perception serves an important function
- Chemicals such as prostaglandins worsen pain by increasing receptor sensitivity to noxious stimuli
  - Aspirin and ibuprofen reduce pain by inhibiting synthesis of prostaglandins

- General **chemoreceptors** transmit information about the total solute concentration of a solution
- Specific chemoreceptors respond to individual kinds of molecules
  - Ex: Osmoreceptors stimulate thirst when osmolarity increases
- **Olfaction** (smell) and **gustation** (taste) both depend on chemoreceptors
  - Smell is the detection of **odorants** carried in the air
  - Taste is detection of **tastants** present in solution

- Humans can distinguish thousands of different odors
- Humans and other mammals recognize just five types of tastants
  - Sweet, sour, salty, bitter, and umami (savory)
- Taste receptors are organized into **taste buds**, mostly found in projections called papillae
  - Any region of the tongue can detect any of the five types of taste!

Figure 38.18

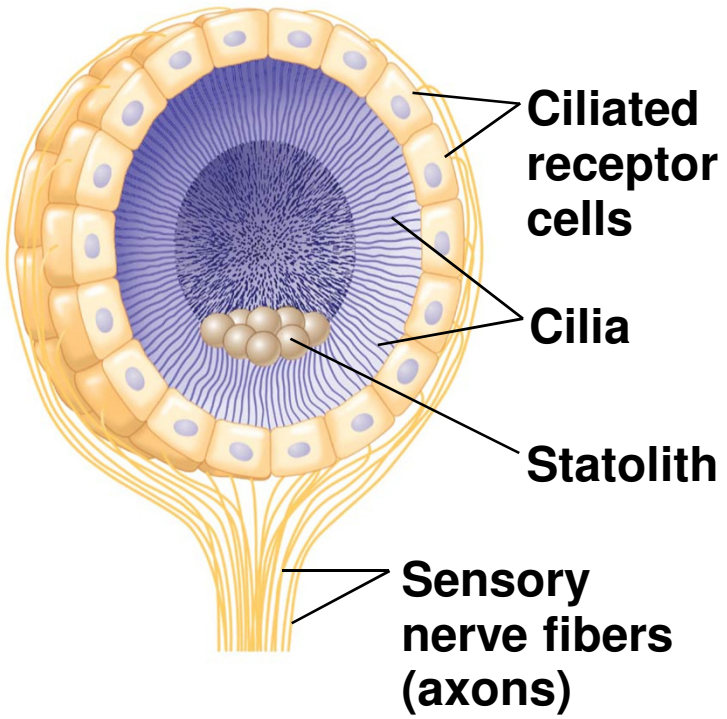

Papilla
Papillae
Tongue
Taste buds
Taste bud
Key
Sweet
Salty
Sour
Bitter
Umami
Taste pore
Food molecules
Sensory neuron
Sensory receptor cells

Concept 38.5: The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles

- Hearing and perception of body equilibrium are related in most animals
- For both senses, settling particles or moving fluid is detected by mechanoreceptors

Sensing of Gravity and Sound in Invertebrates

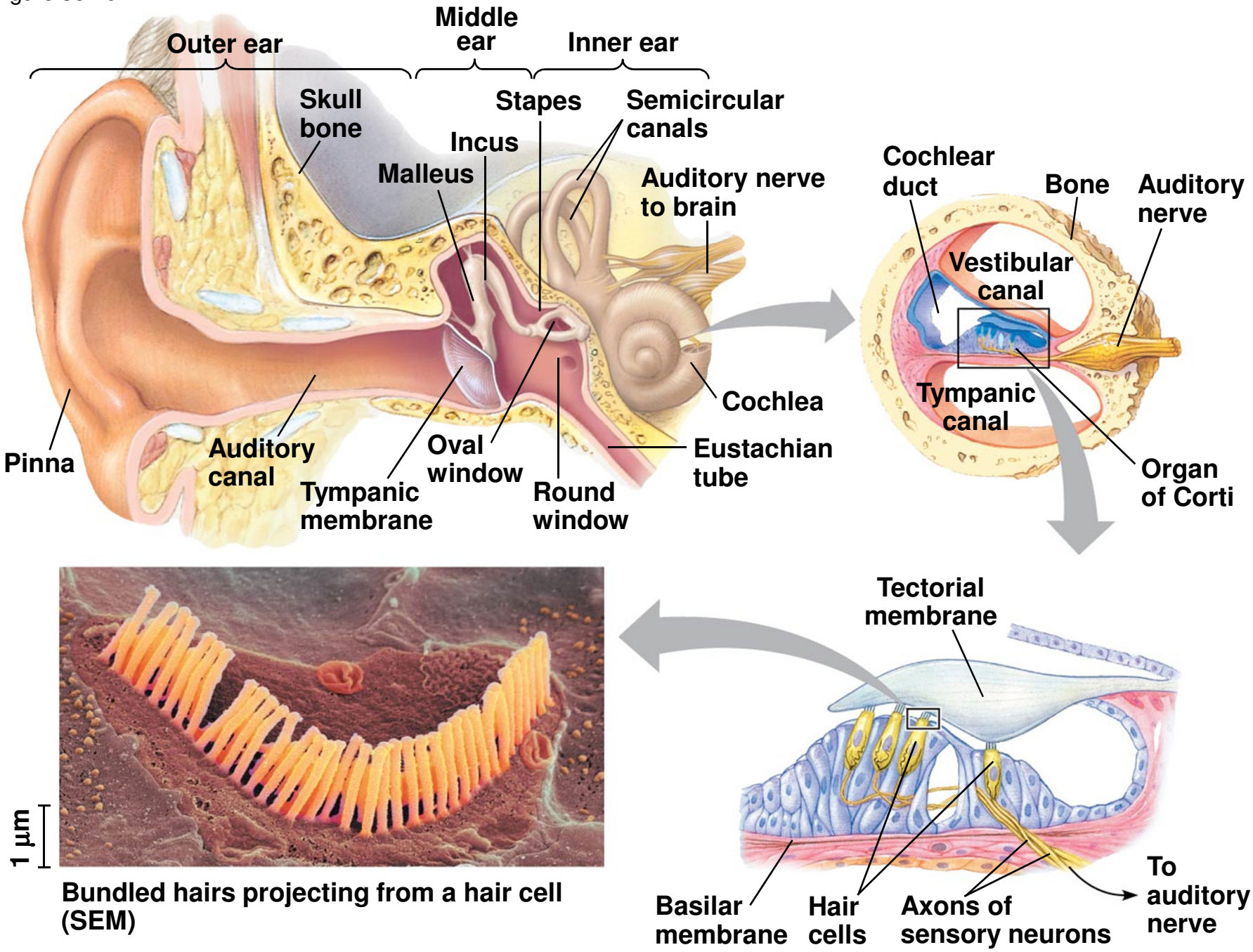
- Most invertebrates maintain equilibrium using mechanoreceptors located in organs called **statocysts**
  - Statocysts contain mechanoreceptors that detect the movement of granules called *statoliths*
- Most insects have body hairs that vibrate in response to sound waves



Hearing and Equilibrium in Mammals

- In most terrestrial vertebrates, sensory organs for hearing and equilibrium are closely associated in the ear

Figure 38.20


Outer ear
Middle ear
Inner ear
Skull bone
Stapes
Semicircular canals
Incus
Malleus
Auditory nerve to brain
Pinna
Auditory canal
Tympanic membrane
Oval window
Round window
Cochlea
Eustachian tube
Cochlear duct
Bone
Auditory nerve
Vestibular canal
Tympanic canal
Organ of Corti
1 µm
Bundled hairs projecting from a hair cell (SEM)
Tectorial membrane
Basilar membrane
Hair cells
Axons of sensory neurons
To auditory nerve

Hearing

- Vibrating objects create pressure waves in the air which are transduced by the ear into nerve impulses, perceived as sound in the brain
- The **tympanic membrane** (eardrum) vibrates in response to vibrations in air
- The vibrations of moving air are transmitted to the **oval window** on the coiled **cochlea** by the three bones of the middle ear
  - Malleus (hammer)
  - Incus (anvil)
  - Stapes (stirrup)

- The vibrations of the bones in the middle ear create pressure waves in the fluid in the cochlea that travel through the vestibular canal
- Pressure waves in the canal cause the basilar membrane to vibrate and attached **hair cells** to vibrate
  - Found in the **organ of Corti**
- Bending of hair cells causes ion channels in the hair cells to open or close
  - Results in a change in auditory nerve sensations that the brain interprets as sound
- The fluid waves dissipate when they strike the **round window** at the end of the vestibular canal
  - Resets apparatus for next round of vibrations

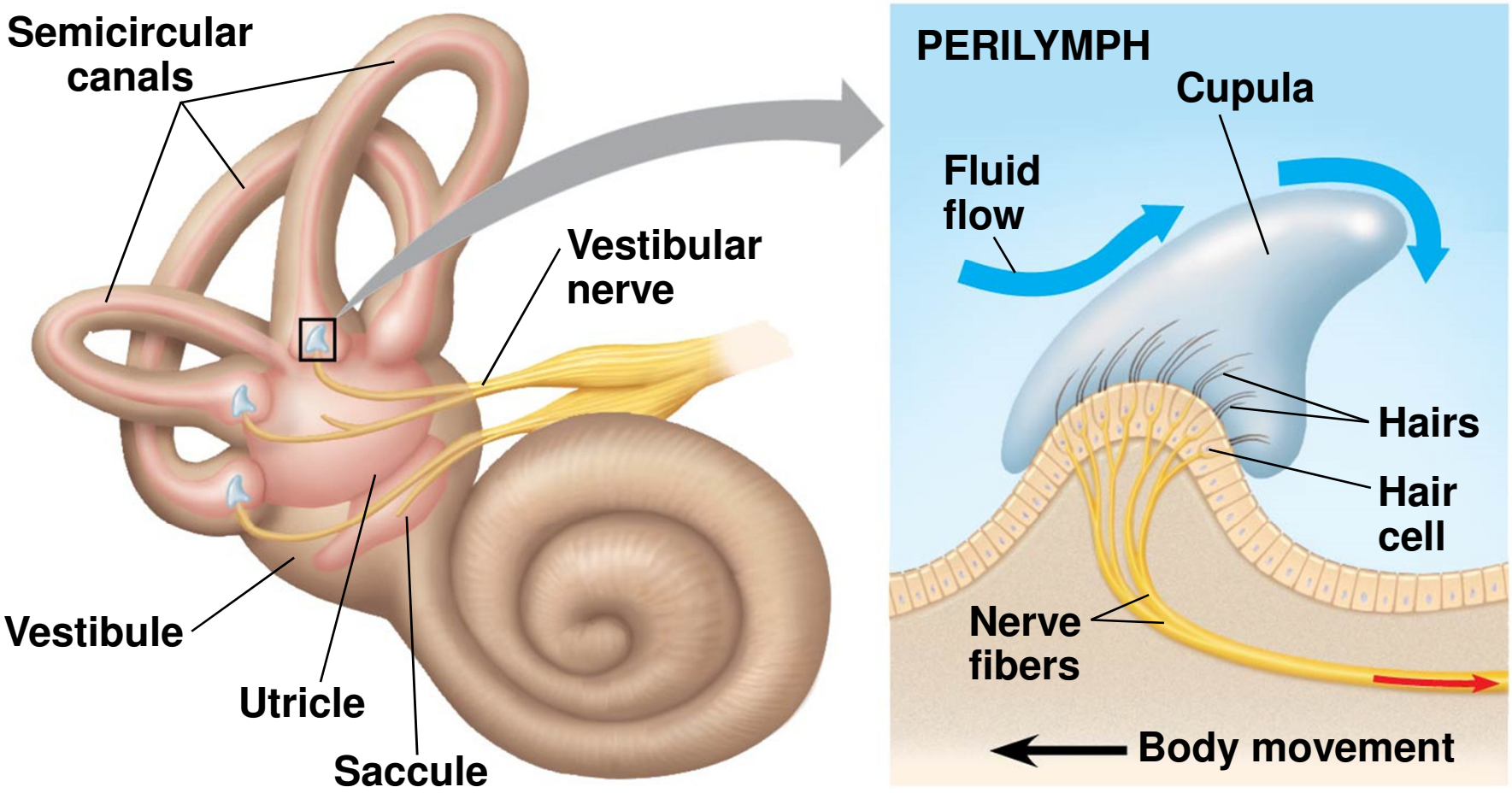
- The ear conveys information about
  - *Volume*
    - Amplitude (or height) of the sound wave
  - *Pitch*
    - Frequency of the sound wave

Equilibrium

- Several organs of the inner ear detect body movement, position, and balance
  - The **utricle** and **saccule** contain granules called otoliths that allow us to perceive position relative to gravity or linear movement
  - Three **semicircular canals** contain fluid and can detect angular movement in any direction

- **Eustachian tube** connects to the pharynx
  - Equalizes pressure between middle ear and atmosphere

Figure 38.22


Semicircular canals
Vestibular nerve
Vestibule
Utricle
Saccule
PERILYMPH
Cupula
Fluid flow
Hairs
Hair cell
Nerve fibers
Body movement

Concept 38.6: The diverse visual receptors of animals depend on light-absorbing pigments

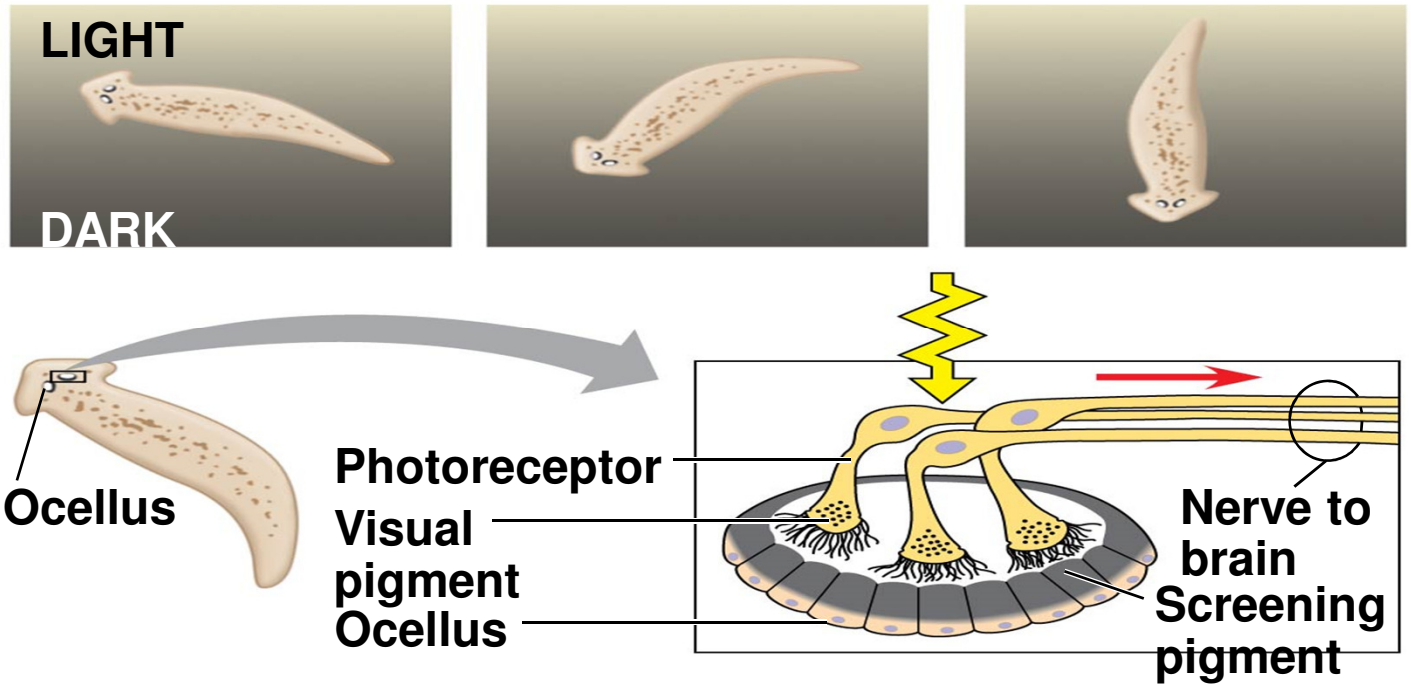
- The organs used for vision vary considerably among animals
  - But the underlying mechanism for capturing light is the same

Evolution of Visual Perception

- Light detectors in animals range from
  - Simple clusters of cells that detect direction and intensity of light
  - To complex organs that form images
- Light detectors all contain **photoreceptors**
  - Cells that contain light-absorbing pigment molecules

Light-Detecting Organs

- Most invertebrates have a light-detecting organ
  - Ex: Planarians have a pair of eyespots located near the heat
    - Allows planarians to move away from light and seek shaded locations



Compound Eyes

- Insects and crustaceans have **compound eyes**
  - Consist of up to several thousand light detectors called **ommatidia**
- Compound eyes are very effective at detecting movement

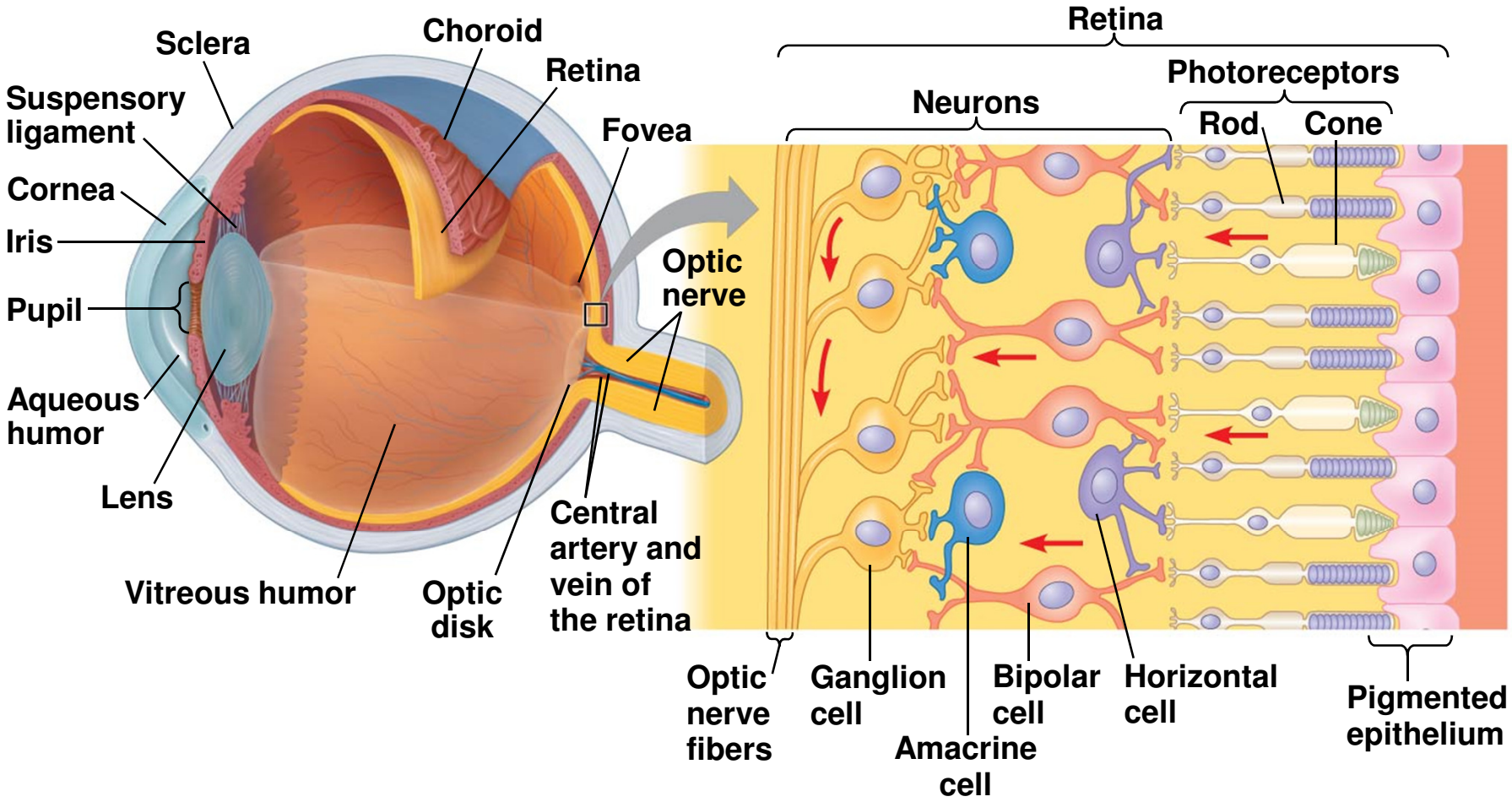
Single-Lens Eyes

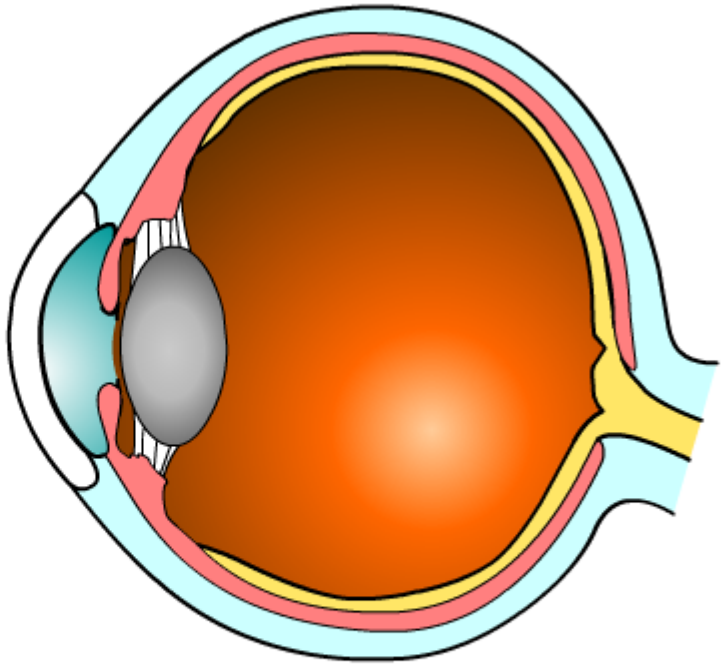
- **Single-lens eyes** are found in some jellies, spiders, and many molluscs
- They work on a camera-like principle
  - **Pupil** is the small opening in the eye through which light can enter
  - **Iris** expands or contracts, changing the diameter of the pupil to control how much light enters
  - A single **lens** focuses light on a layer of photoreceptors located in the **retina**
- The eyes of all vertebrates have a single lens
  - Some focus by moving lends forward or backwards
  - Others, like mammals, change the shape of the lens

The Vertebrate Visual System

- Vision begins when photons of light enter the eye and strike the rods and cones
  - **Rods** are more sensitive to light but do not distinguish colors
  - **Cones** produce color vision but are less sensitive
- However, it is the brain that “sees”

Figure 38.25a





Animation: Near and Distance Vision
Right click slide / Select play

Sensory Transduction in the Eye

- Transduction of visual information to the nervous system begins when light is captured by **retinal**
  - Induces the conversion of *cis*-retinal to *trans*-retinal
  - *Trans*-retinal activates the visual pigment, **rhodopsin**
  - Results in cascade of events that hyperpolarizes cell
- In very bright light, rhodopsin remains active and response in rods becomes saturated
  - If light then decreases rapidly, rods do not regain full responsiveness right away
  - This is the reason why you are temporarily blinded when quickly changing from bright light to darkness

Processing of Visual Information in the Retina

- Processing of visual information begins in the retina
- Rods and cones form synapses with bipolar cells
  - Hyperpolarize or depolarize
  - Effect is reversed when light strikes rods and cones

Processing of Visual Information in the Brain

- The optic nerves meet at the *optic chiasm* near the cerebral cortex
  - Sensations from the left visual field of both eyes are transmitted to the right side of the brain
  - Sensations from the right visual field are transmitted
    to the left side of the brain

Color Vision

- Among vertebrates, most fish, amphibians, and reptiles, including birds, have very good color vision
- Humans and other primates are among the minority of mammals with the ability to see color well
- Mammals that are nocturnal usually have a high proportion of rods in the retina
  - Helps with night vision
- In humans, perception of color is based on three types of cones, each with a different visual pigment:
  - Red, green, or blue

- Abnormal color vision results from alterations in the genes for one or more proteins of visual pigments called *photopsins*
  - The genes for the red and green pigments are located on the X chromosome
  - A mutation in one copy of either gene can disrupt color vision in males

The Visual Field

- The brain processes visual information and controls what information is captured
- Focusing occurs by changing the shape of the lens
- The **fovea** is the center of the visual field
  - Contains no rods but has a high density of cones